HAL
open science

9000 hours-long high temperature annealing of regenerated Fiber Bragg Gratings

Guillaume Laffont, Romain Cotillard, Pierre Ferdinand

▶ **To cite this version:**

Guillaume Laffont, Romain Cotillard, Pierre Ferdinand. 9000 hours-long high temperature annealing of regenerated Fiber Bragg Gratings. Proc. SPIE 8794, Fifth European Workshop on Optical Fibre Sensors, May 2013, Krakow, Poland. pp.87941X, 10.1117/12.2025838 . cea-01823917

HAL Id: cea-01823917

https://cea.hal.science/cea-01823917v1

Submitted on 3 Aug 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ResearchGate

See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/260490492

9000 hours-long high temperature annealing of regenerated Fiber Bragg Gratings

Article *in* Proceedings of SPIE - The International Society for Optical Engineering · May 2013

DOI: 10.1117/12.2025838

CITATIONS
28

READS
467

3 authors:

Guillaume Laffont
Atomic Energy and Alternative Energies Commission
108 PUBLICATIONS **1,334** CITATIONS

SEE PROFILE

Romain Cotillard
Atomic Energy and Alternative Energies Commission
32 PUBLICATIONS **245** CITATIONS

SEE PROFILE

Pierre Ferdinand
Atomic Energy and Alternative Energies Commission
132 PUBLICATIONS **2,169** CITATIONS

SEE PROFILE

Some of the authors of this publication are also working on these related projects:

Project COSMUS View project

All content following this page was uploaded by Guillaume Laffont on 20 May 2014.

The user has requested enhancement of the downloaded file.

9000 hours-long high temperature annealing of regenerated Fiber Bragg Gratings

G. Laffont[1], R. Cotillard and P. Ferdinand
CEA, LIST, Laboratoire de Mesures Optiques, Gif-sur-Yvette cedex, F-91191, France

ABSTRACT

Regenerated Fiber Bragg Gratings have been annealed at high temperatures up to 890°C during 9000 hours in continuous. This test has been conducted in order to experimentally assess the long-term stability of regenerated FBGs dedicated to measurements in high temperature environments. The evolution of both reflectivities and Bragg wavelengths of four wavelength-multiplexed regenerated FBGs simultaneously annealed at respectively 760°C, 810°C, 850°C and 890°C is reported.

Keywords: Regenerated Fiber Bragg Gratings, High temperature, Annealing, Bragg gratings, Optical Fiber Sensors.

1. INTRODUCTION

Thermal processing of standard FBGs under high temperature using the so-called regeneration process opens the way for new metrological applications of FBG sensors dedicated to harsh environments, especially under high temperature up to 900°C [1-3]. The operational and reliable use of regenerated FBGs over long period of time (several hours) for high temperature measurements require to experimentally assess the evolution of their optical characteristics. As the reflectivity of Type I FBGs decreases rapidly at temperature beyond 400°C, their operational lifetime at 900°C prevents their use for long-term metrological application in environments with elevated operational temperatures. Regeneration is a technological breakthrough for high temperature sensing. The reflectivity of regenerated gratings is much more stable than that of standard gratings. But, to our knowledge, no study has been conducted in order to quantify the evolution of the reflectivity and Bragg wavelength of regenerated gratings at high temperature over long period of time. Such inputs are mandatory in order to evaluate the potential of regenerated FBGs for continuous monitoring of structures and processes operating under high temperature and so requiring sensors lifetime of several years. Quantifying the decrease in reflectivity may be useful to anticipate signal-to-noise ratio issues, while quantifying Bragg wavelengths drift is essential to estimate measurement errors.

2. HIGH TEMPERATURE ANNEALING SETUP

2.1 Seed FBGs photowriting

We use a Lloyd interferometric setup to photowrite seed FBGs at an illumination wavelength of 244 nm emitted by a frequency-doubled argon ion laser (FreD Innova 300). Seed gratings used in this study are photowritten in H_2-loaded SMT1310H singlemode fiber (2 weeks at 100 bar, 20°C). Seed gratings are saturated and their length is equal to 5 mm.

2.2 FBG regeneration process

A vertical tubular calibration furnace (TC1200, TecKnow) is used to regenerate the seed FBGs which are introduced in an 8 mm diameter ceramic insert to homogenize internal furnace temperature (see Fig. 1). A type N thermocouple is adjacent to the seed FBGs in order to control the temperature experiences by the gratings during the regeneration. Each grating is inserted in a metallic capillary (1 mm outer diameter). The respective position of the gratings and the thermocouple (TC) is controlled to +/- 1 mm. During the regeneration process, the seed FBGs are pre-annealed at an intermediate temperature of 710°C during two hours. Then the furnace's temperature is raised up to 920°C which is the setpoint triggering the regeneration. Heating is stopped once the reflectivity of the regenerated grating reaches an optimal level.

[1] guillaume.laffont@cea.fr; phone +33 1 69 08 29 38; www.cea.fr

As we use a blind end vertical tubular furnace, the fiber can't be analyzed in transmission. Thus, the spectral behavior of the FBG is monitored in reflection by a spectrometer (Anritsu MS9710C). Even with a flattened ASE source for the FBG monitoring, the residual fluctuation of the spectral power density complicates a direct normalization of the FBG reflected signal during heating ramp. High temperature processing of silica fiber degrades its mechanical resistance. Thus, seed multiplexed FBGs are packaged in a metallic capillary prior to the regeneration to avoid any subsequent bare fiber's manipulation.

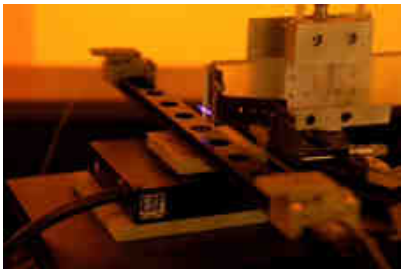

Figure 1. Photowriting of a seed FBG using a Lloyd mirror interferometer.

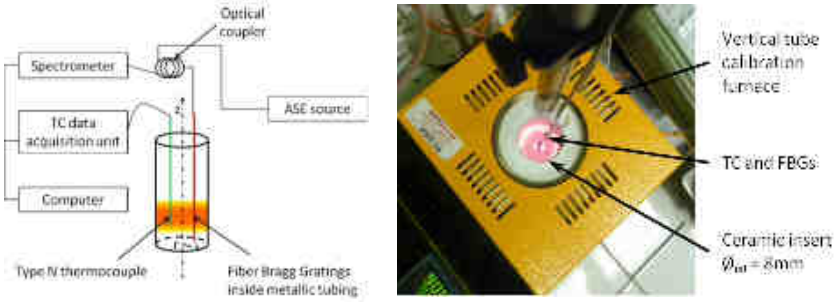

Figure 2. Annealing setup for FBG regeneration (tubular furnace, TC acquisition unit, FBG spectral monitoring).

2.3 Regenerated FBGs annealing setup

To perform the long term annealing experiment, four regenerated FBGs written in a SMT1310H singlemode fiber are inserted in the vertical tubular furnace. Each grating is protected by a metallic capillary (used also during the regeneration). The longitudinal grating position within each capillary is determined using a compact heating element leading to an accuracy of +/- 1 mm [4]. A first bundle made of four regenerated gratings is assembled: distances between gratings are chosen according both to the vertical temperature profile of the tubular furnace and to the annealing temperatures expected for each grating. Then a second bundle made of four TCs is realized: distances between TCs are identical to those between the gratings. The two bundles are then assembled together: each TC is adjacent to a grating in order to control the temperature experiences by each grating during the course of the annealing. The final bundle is then positioned within the furnace and heating is started with a temperature setpoint of 900°C.

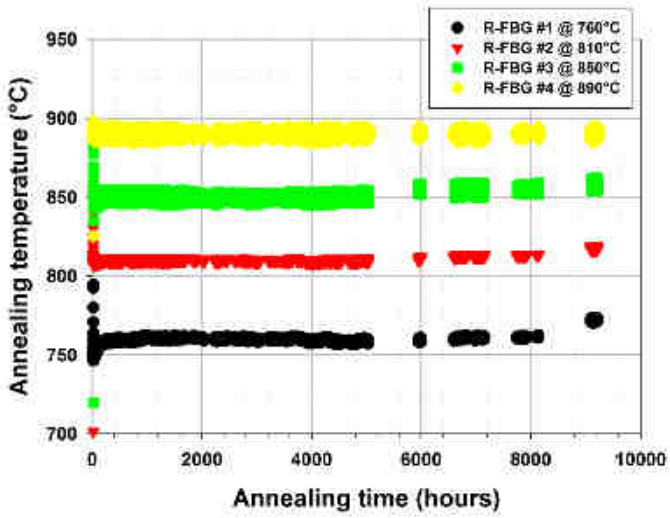

Figure 3. Evolution of the annealing temperatures of the four regenerated FBGs

The annealing has been maintained almost continuously during 9000 hours. It has been stopped only one time during 24 hours (after roughly 4500 hours of operation) in order to calibrate the four regenerated sensors in temperature using the decreasing ramp of the furnace. Then heating has been started again: no significant shift in wavelength before and after

this interruption has been observed. With the exception of this mid-term stop, the blanks in the data are due to pauses during the data acquisition in order to use the spectrometer for other experiments.

To achieve the two lowest annealing temperatures (760°C and 810°C), the gratings have to be positioned close to the top of the furnace heating zone. Thus, we have used accurate type N TC in order to detect any drift in temperature that could be related for instance to a sliding of the bundle. Such a drift is observed at the end of the experiment, especially for the sensor at 760°C with an increase up to 770°C of the annealing temperature experienced by the TC. But such drift is not observed on the Bragg wavelength shift: thus we suppose this slight increase may be only due to a sliding of the bundle containing the four TCs. The two TCs used to measure the temperature at 850°C and 890° are of type K.

3. EXPERIMENTAL RESULTS

3.1 Evolution of the reflectivity

The reflectivities of the four regenerated FBGs are plotted in Figure 4. A rapid decrease is observed during the first 200 hours of annealing at the lowest temperature of 760°C before reflectivity's stabilization to occur. At 890°C, this initial decrease in reflectivity is observed during 50 hours before stabilization. At 890°C, the initial drop in reflectivity reaches 50% and 30% at 760°C. Once initial burn-in is achieved, the amplitudes of the Bragg peaks are much more stable but subsequent evolutions are still observed. The reflectivities tend to decrease again slightly. Of interest is the stabilization occurring for the two gratings at the highest temperature (850°C and especially 890°C) while the reflectivities of the gratings at 80°C and 760°C are still decreasing. In case the two gratings at low temperature follow the same tendancy, this would suggest the possibility to extrapolate behavior at low temperature thanks to experiments carried out at higher temperatures. But this possibility has to be taken with care, and confirmed, because the origin of regeneration is not clearly established. Uncompleted phase transitions within silica might partially explain such evolutions in reflectivity and further experiments are needed to clarify and explain the behavior of regenerated grating's reflectivity under high temperatures. At that time, no model can be applied to predict lifetime of regenerated FBGs except going on with such experimental annealing test. A well-known modelling method for temperature erasable FBGs, the *master curve* formalism [5], has been implemented but it does not work on such regenerated gratings that are temperature resistant. At that time, the results shown in Figure 4 clearly indicate that regenerated FBGs are extremely temperature resistant: they are not erased even after 9000 hours at 890°C.

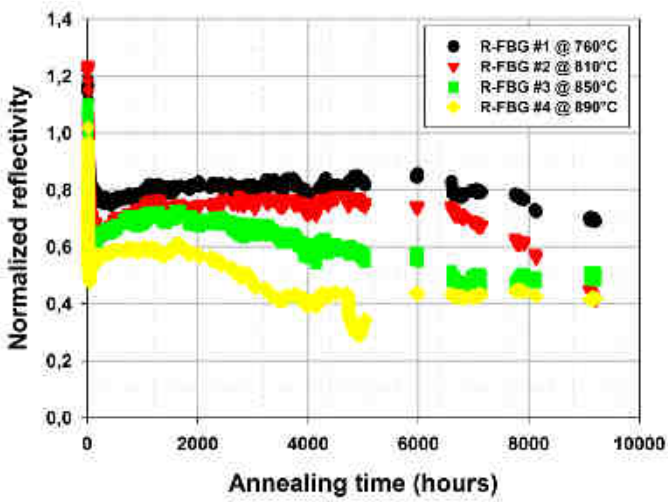

Figure 4. Evolution of the reflectivities of the four regenerated FBGs

3.2 Evolution of the Bragg wavelength shift

In a similar way, the Bragg wavelength shifts experienced by the four regenerated FBGs during the annealing are plotted in Figure 5. A rapid decrease is observed at the beginning of the experiment. The evolutions of the Bragg wavelength shifts are similar but changes seem to be activated by temperature. Taking the grating at 890°C, the initial burn-in is followed by an increase in wavelength, then another decrease and lastly a second increase in wavelength with a turning

point at 3500 hours. From one phase to another the changes occur at a lower rate. The Bragg wavelength shifts are very similar in tendancy for the other gratings. But at 760°C and 810°C, the turning point leading to a second increase in wavelength is not observed. Toggling between decrease and increase in wavelength occurs much faster at high temperature.

Such a behavior has a direct impact on the metrological use of regenerated gratings under high temperature. At 800°C, the thermal sensitivity of the grating R-FBG#4 annealed at 890°C is 16.5 pm/°C. The observed wavelength drift induces an error on the measured temperature. A 500 pm blue shift is experienced by the R-FBG#4 leading to underestimate the temperature by 30°C. Depending on the application, such a behavior has to be anticipated or minimized. This might be achieved by changing the regeneration protocol (annealing temperatures and times) but also by using optical fibers showing other glass composition and/or opto-geometrical parameters. In case such sensors are used to monitor temperature variations instead of the absolute temperature, this long-term drift is of lower importance on the measurement as the sensitivity is almost the same at these two different operating points: 17.0 pm/°C at 800°C and 16.7 pm/°C at 770°C, leading to an error of 1.6% (or 0.17°C) on the temperature step's amplitude.

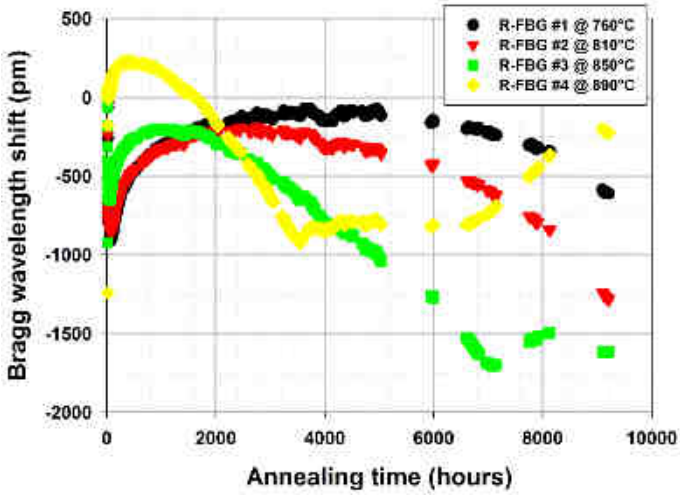

Figure 5. Evolution of the Bragg wavelength shifts of the four regenerated FBGs

4. CONCLUSION AND PERSPECTIVES

Regenerated FBG have been annealed during 9000 hours at temperatures up to 890°C. This experiment illustrates the temperature resistance of such gratings but also the need for further experiments in order to understand the evolution in reflectivities and wavelengths observed during this long-term experiment. Minimizing the spectral drift is mandatory in order to deploy arrays of regenerated FBGs for continuous monitoring of structures and processes. This might be achieved through adjustments of the regeneration parameters but also thanks to optical fibers with other composition and index profiles.

REFERENCES

[1] J. Canning et al., "Extreme silica optical fibre gratings", Sensors, 8 (10), 6448-6452, (2008).

[2] J. Canning et al., "Regenerated gratings", Journal of the European Optical Society, Rapid Publications, 4, (2009).

[3] G. Laffont et al., "Multiplexed regenerated Fiber Bragg Gratings for high temperature measurements", 22nd International Conference on Optical Fiber Sensors, OFS-22, Beijing (China), 15-19 october, (2012).

[4] N. Roussel et al., "Measurement of index modulation along Fiber Bragg Gratings by side scattering and local heating techniques", Opt. Fiber Tech., 5, 119-132, (1999)

[5] B. Poumellec et al., "Precise lifetime predictions using demarcation energy approximation for distributed activation energy reaction", Journal of Physics: Condensed Matter, 7 (18), (2006).

View publication stats